**Title:** The effect of onset threshold on kinetic and kinematic variables of a weightlifting derivative containing a first and second pull.

**Article type:** Original Investigation

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**Running head:** Force-time analysis of a weightlifting derivative

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**ABSTRACT**

This study sought to determine the effect of different movement onset thresholds on both the reliability and absolute values of performance variables during a weightlifting derivative containing both a first and second pull. Fourteen males (age: 25.21±4.14 years; weight: 81.1±11.4 kg; one-repetition maximum [1RM] power clean: 1.0±0.2 $kg \cdot kg^{-1}$) participated in this study. Participants performed the snatch grip pull with 70% of their power clean 1RM, commencing from mid-shank, while isolated on a force platform. Two trials were performed enabling within-session reliability of dependent variables to be determined. Three onset methods were used to identify the initiation of the lift (5% above system weight [SW], the first sample above SW, or 10 N above SW), from which a series of variables were extracted. The first peak phase peak force and all second peak phase kinetic variables were unaffected by method of determining movement onset, however several remaining second peak phase variables were significantly different between methods. First peak phase peak force and average force achieved excellent reliability regardless of the onset method used (CV<5%; ICC>0.90). Similarly, during the second peak phase, peak force, average force and peak velocity achieved either excellent or acceptable reliability (CV<10%; ICC>0.80) in all three onset conditions. The reliability was generally reduced to unacceptable levels at the 1$^{st}$ Sample and 10 N method across all first peak measures except peak force. When analyzing a weightlifting derivative containing both a first and second pull, the 5% method is recommended as the preferred option of those investigated.


Key words: Resistance training, strength, power, testing, data analysis

**INTRODUCTION**

The weightlifting derivatives are considered a primary resistance training modality within strength and conditioning programs (39). Previous research has indicated that training with these exercises has resulted in superior adaptations in strength-power qualities when compared to alternate methods such as jump training (43) traditional resistance training (4) and kettlebell training (33). While a previous study by Helland et al. (19) may contradict the idea that training with weightlifting derivatives is a superior method, it should be noted that a number of limitations, some acknowledged by the authors, may have served as confounding variables. For example, the weightlifting training group in the previous study only included weightlifting exercises (e.g. clean, hang clean, snatch, etc.), a greater overall training volume combined with increased training intensities (near failure or to failure), limited information about the training status of the participants (potential lack of training transfer), and both males and females were both included in the sample. Taken collectively, a greater body of literature supports the notion that weightlifting derivatives produce superior overall training effects when properly programmed. The effective transfer of training stemming from the weightlifting derivatives is a consequence of their ability to overload the triple extension of hips, knees and ankles, span multiple portions of the force-velocity curve (39), while also influencing intermuscular coordination and skill (1, 2, 32).

There are several variants of the weightlifting derivatives that can be employed, each with differing kinetic and kinematic characteristics (39). However, the majority of research into these lifts has focused exclusively on lifts executed from the hang (generally between the knee and mid-thigh) such as the hang power clean (37, 42), jump shrug (36, 42) and hang high pull (38, 42). While there are several advantages to exercises performed from the hang position, including the stimulation of the stretch-shortening cycle, a limitation is the absence of the first pull. In lifts that contain both a first and second pull, larger amounts of force are produced (14, 27, 35) enabling the triple extension to be executed against greater loads (11). The limited research into these lifts may be due, in part, to the complications associated with the numerical integration of force-time data at the initiation of the first pull.

Best practice methods for the collection, processing and analysis of force-time data from strength qualities assessments have become increasingly commonplace in the sports science literature, with attention placed on identifying the initiation of the action of interest (12, 31, 34). For example, the isometric mid-thigh pull (IMTP) requires an accurate determination of the initiation of the pull to reliably calculate rate dependent variables. A number of methods have been reported including fixed values such as 20 N or 40 N above baseline, or a change of >5SDs during the initial weighing period, with the latter suggested as the preferred approach (12). When analysing a countermovement jump (CMJ) force-time trace, the point at which to commence the analysis will impact the integration process resulting in changes to the derived velocity and power measures. The threshold values for this test have included the instant at which force is reduced by 4 × the SD of BW (24) or an arbitrary reduction in force (e.g. >10N) (13). Recently, 30 ms before a 5 × SD of BW decrease in the force-time curve has been suggested as the criterion method, since it retains the entire jump signal while minimizing any capture of the stance phase (34).

A common requirement across these force-time curve analyses is a stable period of consistently applied force preceding the action in a trial (referred to as the weighing phase)(5, 12, 30). While this is generally easy to achieve, the realities of performance testing in high pressure applied settings are such that 'clean' data is not always gathered. The ability to capture a weighing phase prior to movement onset are reduced further when weightlifting derivatives containing a first pull are being analysed due to the starting position required. If data is acquired by a force platform, the lifter + barbell system must not be in contact with any other surface (e.g. plates on the floor)(8, 9, 23). This ensures that system mass is unchanged allowing velocity to be calculated via numerical integration of the force-time curve. It is recommended then that lifts incorporating the first pull must therefore be performed from approximately from mid-shank instead of the floor(23). However, considering the position of the lifter and the loads involved, it can be challenging for the performer to maintain a stable period of force application before the initiation of the pull. Consequently, conventional approaches to movement identification such as those used in the CMJ and IMTP may not be feasible. Understanding the impact of different methods for identifying movement onset during a weightlifting derivative with both a first and second pull will enable practitioners and sports scientists to better explore the mechanical characteristics of these lifts. Despite the benefits associated with reliable analysis of such exercises, there are no known studies into this topic, and limited research in general into exercises such as the snatch pull and clean pull (14, 39). Therefore, it is the purpose of this investigation to examine the impact of different movement onset thresholds (5% above system weight [SW], the first sample above SW, or 10 N above SW) on the reliability of common performance variables during a weightlifting derivative containing both a first and second pull when lifting from mid-shank. Additionally, the influence of weightlifting ability (as assessed by the 1RM power clean) on these reliability measures will also be explored. It was hypothesized that a larger onset threshold (in this case the 5% above SW) would improve the reliability of measures extracted from the force-time record of such a lift, and that greater reliability will be displayed by the stronger participants.

## METHODS

### *Experimental Approach to the Problem*

The impact of different first-pull onset thresholds on the reliability a series of force, velocity and power measures during a weightlifting pulling derivative were examined using a cross-sectional within- and between-subjects design. All participants attended a single testing session which was initiated with a standardized general then specific dynamic warmup. Participants performed two non-consecutive maximal effort snatch-grip pulls (SGPs) from mid-shank at 70% of their predetermined power clean 1RM. Additionally, participants were stratified based on their relative 1RM power clean result to determine the influence of weightlifting ability on the reliability of the dependent variables.

### *Participants*

Fourteen recreationally trained males (age: 25.21 ± 4.14 years; weight: 81.1 ± 11.4 kg; height: 1.79 ± 0.09 m; 1RM power clean: 1.0 ± 0.2 kg·BM$^{-1}$) who had been undertaking at least 6 weeks of instructed resistance training with the weightlifting derivatives, including SGPs, participated in this study. All participants provided written informed consent and the study was approved by the institute’s human research ethics committee (2016-04-269).

*Testing Procedures*

Testing occurred >72 hours following any training sessions. Before testing, participants completed a warmup consisting of several unweighted activities including squats at increasing depth, alternating lunges and sub-maximal countermovement jumps and hops at increasing intensities. Participants then completed the SGP at progressively increasing loads. This exercise is typically completed from the floor, however during the present investigation it was executed from mid-shank level. This resulted in the entire mass of the barbell-lifter system being projected through the feet of the lifter. Following completion of all warmup activities, participants had three minutes of passive recovery before undertaking at least two maximal effort trials at 70% of their predetermined 1RM power clean. Each trial was separated by two minutes of passive recovery. Participants were instructed to keep the bar as still as possible before performing the trial with maximal intent. The bar was positioned at mid-shank as determined via observation by the chief investigator. This qualitative approach enabled an increased ecological validity which was necessary for this investigation. Participants were cued to keep the arms straight until the triple extension was completed, and shrug at the top of the movement. In addition, the lifter was permitted to jump if the effort resulted in it. All trials were performed with the barbell-lifter system isolated on a force platform (Bertec Corporation, Columbus, OH, USA) with the data sampled at 2000 Hz via a data acquisition device (NI USB-6259 BNC, National Instruments) and processed using a custom LabVIEW program (V.12.0f3, National Instruments). Data were then saved off-line for secondary processing.

*Data Analysis*

A custom designed spreadsheet (Excel, version 2016, Microsoft Corp., Redmond,WA, USA) was used to calculate the dependent variables from the raw force-time data. The initiation of the lift was identified as the point at which the force-time curve increased by: i) 5% above SW; ii) the first sample above SW; or iii) 10 N above SW. The end of the lift occurred at the lowest point on the curve >20 N. The force-time data was then numerically integrated between lift initiation and lift completion to generate a velocity-time record. This was achieved by dividing net force (vertical force - SW) by system mass and then integrating the product using the trapezoid rule on a sample-by-sample basis. The product of the force and velocity at each sample produced a power-time curve. Two distinct peaks occur during the SGP, which were used as events to denote force-time phases of the lift. The end of the first peak phase was identified as the first peak in force, while the end of the unweighting phase (i.e. start of the second peak) occurred at the first increase in force preceding the second peak (Figure 1). These phases were defined as they represented objective events that could be clearly identified in the force-time record in the absence of motion capture data previously used in earlier investigations (14, 15). First peak mean rate of force development (RFD) was calculated as the change in force with respect to time between the initiation and end of the first peak phase. This metric was also calculated between the start of second peak phase and the highest force value in that phase. Peak force, -velocity and –power was indicated by the highest respective sample in the first and second peak phases. Average force, -velocity and -power were calculated over the entire duration of the first peak phase. During the second peak phase, these variables were calculated between the start of this phase and the point at which the force-time curve dropped below SW. This instant represents the onset of the propulsion deceleration phase whereby the velocity of the system begins to reduce until the momentary pause (i.e. zero velocity) attained at the end of the second peak phase (Figure 1).

***Place Figure 1 About Here***

*Statistical Analyses*

Data were normally distributed except for the following variables: peak velocity and peak power in the first peak phase, and average force and RFD during the second peak phase. Where normality was met a repeated measures ANOVA (group × onset condition) was executed with a post-hoc Bonferroni correction to locate the presence of a difference in a given dependent variable between the three onset methods during the first trial. A Friedman's test was administered for non-normally distributed variables followed by a Wilcoxon Signed Ranks test with a Bonferroni correction. An Alpha level of $p \leq 0.05$ represented statistical significance. Cohen's *d* effect size calculations were performed to compare the magnitude of difference in dependent variables between trials, with thresholds set at <0.2, 0.21-0.5, 0.51-0.8 and >0.8 for trivial, small, moderate and large magnitudes of effect, respectively . When assessing between trial reliability for each onset method data were analyzed using Microsoft Excel (version 2016, Microsoft Corp., Redmond,WA, USA) and are presented as group mean values ± SD. Reliability was assessed using a coefficient of variation (CV) and intraclass correlation coefficient (ICC) with associated 90% confidence intervals (90% CI) (22). High reliability was deemed as a CV <5% and an ICC > 0.90. An acceptable threshold of reliability was set at a CV of <10% and an ICC of >0.80 (25). Paired comparisons with a significance of $p \leq 0.05$ was used to compare dependent variables between the two trials within each onset condition. To determine the impact of weightlifting ability on reliability, the cohort was stratified into two groups based on their 1RM power clean result (Stronger: 1RM power clean > 1 × BM, n = 6; age: 24.67 ± 4.37 years; weight: 79.72 ± 2.25kg; height: 1.74 ± 0.05 m; Weaker: 1RM power clean ≤ 1 × BM, n = 8; age: 26.5 ± 3.12 years; weight: 82.15 ± 14.85 kg; height: 1.82 ± 0.08 m). Reliability was assessed at both the whole cohort, and stratified group level. The CV and ICC, in addition to their associated CI, were calculated using a custom-designed spreadsheet (25). The Statistical Package for Social Sciences (version 22; IBM, New York) was used to analyze all remaining data.

## RESULTS

The means and SD for all dependent variables in both trials at the 5%, 1st Sample and 10 N onset thresholds are presented in Tables 1, 2 and 3 respectively. Figures 2, 3 and 4 depict the CV and ICC for the dependent variables across all three onset thresholds for the entire group, and when stratified by strength level. First peak phase peak force and all second peak phase kinetic variables were unaffected by method of movement onset, while the impact on the remaining second peak phase variables were negligible. At the whole group level, first peak phase peak force and average force achieved excellent reliability regardless of the onset method used. Similarly, during the second peak phase, peak force, average force and peak velocity achieved either excellent or acceptable reliability in all three onset conditions. In the 5% method the stronger participants achieved acceptable reliability across all dependent variables except for first peak RFD, second peak RFD and average power. The reliability was generally reduced to unacceptable levels at the 1st Sample and 10 N method across all first pull measures except peak force. A similar pattern was seen within the weaker participants although with mostly lower levels of reliability overall when compared to the stronger group.

*** Place Table 1 About Here***

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**DISCUSSION**

The aim of this study were to assess the influence of different onset thresholds on the reliability of kinetic and kinematic variables during a weightlifting derivative containing both a first and second pull. The primary finding was that the method used to identify the initiation of the lift (and therefore commence the analysis) had a considerable impact on the reliability of measures of system velocity, power and RFD during the first peak phase. Specifically, of the three approaches examined, the 5% above SW threshold resulted in generally improved reliability across all such measures, particularly for the stronger group. It should be noted, however, that at the whole group level the only variables to achieve reliability were second peak phase peak velocity, and peak and average force across both peak phases. These findings illustrate the difficulty of conducting force platform assessments of weightlifting variations that include the first pull (where the barbell must be held slightly off the ground), if other variables such as power and velocity of the system are of interest. Nevertheless, the present study has illustrated how selecting an appropriate onset threshold can lead to improved reliability of these data.

The major limitation with the first sample method was that the participants often applied force slighter greater than that of SW when attempting to maintain a stable bar before the lift was properly initiated. This is, indeed, a problem that is induced by not being able to commence the lift from the floor due to the requirement to account for entire SW as part of force-time data analyses procedures. Furthermore, it can be expected that the difficulty in stabilizing the bar would be increased under additional load and will consequently limit the relative load that can be used. As RFD and all remaining average variables are calculated directly from this instant, incorrect identification of initiation of the lift have a major impact on the accuracy of the values attained. An additional disadvantage of this method is the impact it has on velocity. The onset point indicates the start of motion of the system and therefore influences the velocities (peak and average) attained, particularly in the first peak phase. For example, in the first sample method it is more likely (due to the low force threshold) that numerical integration of the force-time record commences before the actual initiation of the lift, consequently affecting the calculation of velocity, which will subsequently affect the calculation of power. Any inaccuracies associated with velocity and power calculations in the first peak phase, despite this phase not eliciting ‘high’ velocity and power values, will continue into the second peak phase, thus rendering these and similar calculations made throughout the entire SGP meaningless. It should be noted that although ‘maximal’ acceleration and velocity is not the focus of the first pull (as noted in considerably lower power outputs in this and other investigations (16, 21)), if technique is maintained, this may result in greater velocity and displacement and therefore increase the kinetic and kinematic outputs during the lift, or result in an increased load lifted.

Many of the issues present in the first sample method are largely overcome in the 10 N and 5% thresholds. The advantages to these approaches are that the analysis commences after any erratic movement of the system preceding the major force application at the beginning of the lift. As 5% of SW in this present investigation represented 67 ± 10.20 N, further unstable ground reaction force prior to the initiation of the exercise was avoided, and reliability generally improved further when compared to the 10 N threshold. However, the improvements in reliability between the 10 N and 5% methods were not as marked as those noted between the first sample and 10 N approaches. Performing the SGP with a SW greater than what was used in the present study would likely increase the chances of a 10 N threshold being prematurely exceeded before the lift is initiated (i.e. doubling SW would effectively half the 10 N threshold when expressed as a percentage of the SW). Thus, the 5% method is likely the most sensible option from those included in the present study, but further research is required to determine if this approach remains the most appropriate across a range of loads in the SGP.

None of the onset thresholds included in the present study accounted for the noise in the force signal that would be generated by the force platform itself (i.e. residual force) throughout the entire data collection period and by the subjects themselves during the weighing period (i.e. before initiating the movement). This is usually achieved by establishing SW (or BW, if performing a BW-only task) over at least a one second duration prior to the onset of movement and then calculating an onset force threshold based on five times the SD of the established SW. Utilizing a 5SD of SW approach, similar to the 5SD of BW approach advocated for IMTP (12) and CMJ (34) force-time testing, was not possible in the present study, however, due to subjects having to commence the lift whilst holding the barbell off the floor at mid-shank level. If, however, researchers use force platforms that are large enough to accommodate both the subject and barbell in the start position of any weightlifting derivatives that commence from the floor, they should consider comparing the 5SD of SW approach to the 5% method used in the present study. The 5SD of SW onset threshold approach should also be considered when performing force platform assessments of weightlifting variations from the knee (i.e. hang position) or above (i.e. mid-thigh level), given that it is much easier to maintain a stable position (and thus, establish SW from the force-time record) before executing such lifts. Further research could explore the benefits and limitations of alternate methods for processing force-time data of lifts with a first and second pull. This may include collecting a standing weighing period, to obtain system weight, before and after the lift, yet within the same force-time record. However, such methods will be susceptible to integration drift due to the large capture period.

The results from the current study indicate that stronger individuals appear to demonstrate greater reliability when it comes to producing force-, velocity-, and power-time data during the SGPs performed, regardless of the threshold method used. Although not examined in the current study, stronger individuals may have been able to replicate their technique compared to weaker individuals. Because muscular strength benefits an individual's performance in a number of ways, including maintaining posture (40), it is possible that stronger individuals can produce greater performance outcomes despite potential flaws within their technique compared to weaker individuals (20). Although limited longitudinal research on the performance of weightlifting variations following changes in technique exists (18, 44), Winchester et al. (44) et al. demonstrated considerable improvements in power snatch bar-path kinematics following only four weeks of training with the weightlifting derivatives. Furthermore, superior reliability in weightlifting performance has been previously reported amongst stronger versus weaker Olympic level weightlifters (29).

The current study is the first study to compare different starting thresholds during a weightlifting variation and should, therefore, serve as hypothesis generating research. As mentioned above, a common issue that arises when examining weightlifting variations that typically start from the floor (e.g. power clean, clean/snatch pull from the floor, etc.) is the fact that the entire system mass is not taken into account on the force platform prior to the start of the lift. As a result, much of the research examining weightlifting variations has been performed from a hang position (e.g. mid-thigh, the knee, or below the knee) (37, 41). The current study and previous studies (6, 7) have circumvented this issue by starting the lifts from a paused position at the mid-shank after the load has been lifted slightly off the ground. It should be noted that two studies (10, 28) were able to examine the external power output produced solely from ground reaction force data during the clean exercise. However, it is unclear what starting thresholds were used to identify the start of each lifting phase.

It is important to note that the phases of the SGP (first peak, unweighting, , second peak) in the present study were identified solely on the intact force-time curve. Although this approach enabled an objective identification of the phases using only GRF data, the segmental position of the lifter is needed to precisely define the pull phases. Previous research within weightlifting (3, 15-17, 26) have utilized joint and barbell kinematics to define specific phases of the snatch. For example, Harbili and Alptekin (17), amongst others (3, 15, 26) defined 5 phases of the snatch, with the pull and transition portions being described as; lift-off to first maximum knee extension ($1^{st}$ pull), first maximum knee extension to first maximum knee flexion (transition) and first maximum knee flexion to second maximum knee extension ($2^{nd}$ pull). This indicates that knee joint kinematics are a key criterion in defining the phases of the pull.

A limitation of this present study was that no 3D motion capture system was used to identify moments occurring in the knee joint, therefore the authors were unable to identify the phases using methods previously mentioned. However, a standardized objective method using solely GRF data was used to identify key phases of the lift. . Using objective points on the force-time curve allows future research to standardize methods when measuring weightlifting pulling movements. Furthermore, as the kinetic and kinematic behavior of the entire system is generally of greater relevance to the strength and conditioning coach, it seems practical to establish procedures for identifying phases from GRF data in the absence of motion capture. It would be of interest to practitioners for future research to explore, in detail, methods of weightlifting phase identification derived from GRF data alone, and to establish how this compares to combined methods of joint and barbell kinematics along with GRF data.

## PRACTICAL APPLICATIONS

Analyzing changes in the force-time curve of the weightlifting derivatives can yield valuable mechanistic information on lift performance. However, to do so requires suitable data processing techniques that produce reliable measures of performance. The results from the current study indicate a considerably improved reliability using the 10 N and 5% method, when compared to the first sample procedure. However, the 5% method is recommended as the preferred option as it is proportional to the load being lifted. Finally, practitioners can expect that as performance in the weightlifting derivatives improves, so too does the reliability of the kinetic and kinematic variables acquired from such a lift.

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**FIGURE LEGENDS**

Figure 1. A typical force-time record of a snatch grip pull performed from mid-shank with a load of 70% of the individual's power clean one repetition maximum. Overlaid is the associated velocity-time (A) and power-time curves (B). The dashed vertical lines represent the lift phases derived from objective events within the intact force-time record alone. In this example, the lifter has a body mass of 83.3 kg, and the bar mass is 72.5 kg.

Figure 2. Reliability (+/- 90% confidence intervals) of kinetic and kinematics variables derived from the snatch grip pull at 70% of the power clean one repetition maximum using an onset threshold of 5% above system weight across all participants. The light shading indicates high reliability while the dark shading indicates acceptable reliability. The horizontal dotted line distinguishes the first and second peak variables (above: first peak, below: second peak). RFD: Rate of force development. ICC: Intraclass correlation coefficient.

Figure 3. Reliability (+/- 90% confidence intervals) of kinetic and kinematics variables derived from the snatch grip pull at 70% of the power clean one repetition maximum using an onset threshold of 5% above system weight across the strongest and weakest participants. The light shading indicates high reliability while the dark shading indicates acceptable reliability. The horizontal dotted line distinguishes the first and second peak variables (above: first peak, below: second peak). RFD: Rate of force development. ICC: Intraclass correlation coefficient.

Figure 4. Reliability (+/- 90% confidence intervals) of kinetic and kinematics variables derived from the snatch grip pull at 70% of the power clean one repetition maximum using an onset threshold of the first sample above system weight across all participants. The light shading indicates high reliability while the dark shading indicates acceptable reliability. The horizontal

dotted line distinguishes the first and second peak variables (above: first peak, below: second peak). RFD: Rate of force development. ICC: Intraclass correlation coefficient.

Figure 5. Reliability (+/- 90% confidence intervals) of kinetic and kinematics variables derived from the snatch grip pull at 70% of the power clean one repetition maximum using an onset threshold of the first sample above system weight across the strongest and weakest participants. The light shading indicates high reliability while the dark shading indicates acceptable reliability. The horizontal dotted line distinguishes the first and second peak variables (above: first peak, below: second peak). RFD: Rate of force development. ICC: Intraclass correlation coefficient.

Figure 6. Reliability (+/- 90% confidence intervals) of kinetic and kinematics variables derived from the snatch grip pull at 70% of the power clean one repetition maximum using an onset threshold of 10 N above system weight across all participants. The light shading indicates high reliability while the dark shading indicates acceptable reliability. The horizontal dotted line distinguishes the first and second peak variables (above: first peak, below: second peak). RFD: Rate of force development. ICC: Intraclass correlation coefficient.

Figure 7. Reliability (+/- 90% confidence intervals) of kinetic and kinematics variables derived from the snatch grip pull at 70% of the power clean one repetition maximum using an onset threshold of 10 N above system weight across the strongest and weakest participants. The light shading indicates high reliability while the dark shading indicates acceptable reliability. The horizontal dotted line distinguishes the first and second peak variables (above: first peak, below: second peak). RFD: Rate of force development. ICC: Intraclass correlation coefficient.

**TABLE LEGENDS**

Table 1. Comparison of kinetic and kinematic snatch grip pull variables between trial 1 and trial 2 using 5% above system weight as the onset threshold. *Significant difference between trial 1 and 2.

Table 2. Comparison of kinetic and kinematic snatch grip pull variables between trial 1 and trial 2 using the first sample above system weight as the onset threshold. [a] Significant difference between 5% and 1st sample method. *Significant difference between trial 1 and 2.

Table 3. Comparison of kinetic and kinematic snatch grip pull variables between trial 1 and trial 2 using 10 N above system weight as the onset threshold. [b] Significant difference between 1st sample method and 10 N method. [c] Significant difference between 5% method and 10 N. * Significant difference between trial 1 and 2.